

UTILITY PATENT APPLICATION TRANSMITTAL (Small Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.
ML-0459C

Total Pages in this Submission
38

TO THE ASSISTANT COMMISSIONER FOR PATENTS

Box Patent Application
Washington, D.C. 20231

Transmitted herewith for filing under 35 U.S.C. 111(a) and 37 C.F.R. 1.53(b) is a new utility patent application for an invention entitled:

IMAGING SYSTEM USING POLARIZATION EFFECTS TO ENHANCE IMAGE QUALITY

and invented by:

James M. Zavislan

1c886 U.S. PRO
09/641795



If a CONTINUATION APPLICATION, check appropriate box and supply the requisite information:

☒ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: 08/966,046

Which is a:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.:

Which is a:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.:

Enclosed are:

Application Elements

1. ☒ Filing fee as calculated and transmitted as described below
2. ☒ Specification having 16 pages and including the following:
 - a. ☒ Descriptive Title of the Invention
 - b. ☐ Cross References to Related Applications (if applicable)
 - c. ☐ Statement Regarding Federally-sponsored Research/Development (if applicable)
 - d. ☐ Reference to Microfiche Appendix (if applicable)
 - e. ☒ Background of the Invention
 - f. ☒ Brief Summary of the Invention
 - g. ☒ Brief Description of the Drawings (if drawings filed)
 - h. ☒ Detailed Description
 - i. ☒ Claim(s) as Classified Below
 - j. ☒ Abstract of the Disclosure

UTILITY PATENT APPLICATION TRANSMITTAL (Small Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

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38

Application Elements (Continued)

3. ☒ Drawing(s) (when necessary as prescribed by 35 USC 113)
- a. ☒ Formal b. ☐ Informal Number of Sheets 4
4. ☒ Oath or Declaration
- a. ☐ Newly executed (original or copy) ☐ Unexecuted
- b. ☒ Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional application only)
- c. ☒ With Power of Attorney ☐ Without Power of Attorney
- d. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application,
see 37 C.F.R. 1.63(d)(2) and 1.33(b).
5. ☒ Incorporation By Reference (usable if Box 4b is checked)
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied
under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby
incorporated by reference therein.
6. ☐ Computer Program in Microfiche
7. ☐ Genetic Sequence Submission (if applicable, all must be included)
- a. ☐ Paper Copy
- b. ☐ Computer Readable Copy
- c. ☐ Statement Verifying Identical Paper and Computer Readable Copy

Accompanying Application Parts

8. ☒ Assignment Papers (cover sheet & documents) (copy from prior application).
9. ☐ 37 CFR 3.73(b) Statement (when there is an assignee)
10. ☐ English Translation Document (if applicable)
11. ☐ Information Disclosure Statement/PTO-1449 ☐ Copies of IDS Citations
12. ☒ Preliminary Amendment
13. ☒ Acknowledgment postcard
14. ☒ Certificate of Mailing
- ☐ First Class ☒ Express Mail (Specify Label No.): EL641551931US

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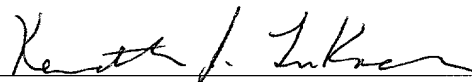
**UTILITY PATENT APPLICATION TRANSMITTAL
(Small Entity)***(Only for new nonprovisional applications under 37 CFR 1.53(b))*Docket No.
ML-0459CTotal Pages in this Submission
38**Accompanying Application Parts (Continued)**

15. ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. ☒ Small Entity Statement(s) - Specify Number of Statements Submitted: 1
(copy from prior application)
17. ☐ Additional Enclosures *(please identify below)*:

Fee Calculation and Transmittal**CLAIMS AS FILED**

For	#Filed	#Allowed	#Extra	Rate	Fee
Total Claims	14	- 20 =	0	x \$9.00	\$0.00
Indep. Claims	3	- 3 =	0	x \$39.00	\$0.00
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>					\$0.00
BASIC FEE					\$345.00
OTHER FEE (specify purpose) _____					\$0.00
TOTAL FILING FEE					\$345.00

- ☒ A check in the amount of **\$345.00** to cover the filing fee is enclosed.
- ☒ The Commissioner is hereby authorized to charge and credit Deposit Account No. **50-1101** as described below. A duplicate copy of this sheet is enclosed.
- ☐ Charge the amount of _____ as filing fee.
- ☒ Credit any overpayment.
- ☒ Charge any additional filing fees required under 37 C.F.R. 1.16 and 1.17.
- ☐ Charge the issue fee set in 37 C.F.R. 1.18 at the mailing of the Notice of Allowance, pursuant to 37 C.F.R. 1.311(b).

Dated: **August 18, 2000**
Signature

Kenneth J. LuKacher
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KJL/tsm
CC:

CERTIFICATE OF MAILING BY "EXPRESS MAIL" (37 CFR 1.10)Applicant(s): **James M. Zavislan**

Docket No.

ML-0459C

Serial No.

N/A

Filing Date

Concurrently herewith

Examiner

N/A

Group Art Unit

N/A

Invention: **IMAGING SYSTEM USING POLARIZATION EFFECTS TO ENHANCE IMAGE QUALITY**

I hereby certify that the following correspondence:

Continuation Application*(Identify type of correspondence)*

is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 in an envelope addressed to: The Assistant Commissioner for Patents, Washington, D.C. 20231

August 18, 2000*(Date)***Tammy S. Moynihan***(Typed or Printed Name of Person Mailing Correspondence)**(Signature of Person Mailing Correspondence)***EL641551931US***("Express Mail" Mailing Label Number)*

Note: Each paper must have its own certificate of mailing.

**VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY
STATUS (37 CFR 1.9(f) AND 1.27 (c)) - SMALL BUSINESS CONCERN**

Docket No.
ML-0459

Serial No.

N/A

Filing Date

Concurrently herewith

Patent No.

N/A

Issue Date

N/A

Applicant/ **James M. Zavislan**
Patentee:

Invention: **IMAGING SYSTEM USING POLARIZATION EFFECTS TO ENHANCE IMAGE QUALITY**

I hereby declare that I am:

- ☐ the owner of the small business concern identified below:
- ☒ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF CONCERN: Lucid Technologies, Inc.ADDRESS OF CONCERN: 235 Middle Road, Henrietta, NY 14467

I hereby declare that the above-identified small business concern qualifies as a small business concern as defined in 37 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under Section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the above identified invention described in:

- ☒ the specification filed herewith with title as listed above.
- ☐ the application identified above.
- ☐ the patent identified above.

If the rights held by the above-identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed on the next page and no rights to the invention are held by any person, other than the inventor, who could not qualify as an independent inventor under 37 CFR 1.9(c) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

- ☒ no such person, concern or organization exists.
☐ each such person, concern or organization is listed below.

FULL NAME

ADDRESS

☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

FULL NAME

ADDRESS

☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

FULL NAME

ADDRESS

☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

FULL NAME

ADDRESS

☐ Individual ☐ Small Business Concern ☐ Nonprofit Organization

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING:

James M. Zavislan

TITLE OF PERSON SIGNING

OTHER THAN OWNER:

Vice-president

ADDRESS OF PERSON SIGNING:

5 Wandering Trail
Pittsford, NY 14534

SIGNATURE:

James M. Zavislan

DATE:

7 November 1997

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Zavislan
Application No: Continuation of USSN 08/966,046, filed Nov. 7, 1997
Filed: Concurrently herewith
Title: IMAGING SYSTEM USING POLARIZATION EFFECTS TO
ENHANCE IMAGE QUALITY
Examiner: Pham, H. Art Unit: 2877
Attorney Docket: ML-0459C

PRELIMINARY AMENDMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

Please amend the above-identified application as follows:

In the Abstract:

Line 21, before "shift", insert -- phase --.

In the Specification:

Page 1, at line 3, insert the paragraph --This application is a continuation of Application Serial No. 08/966,046, filed November 7, 1997, now pending--.

Page 1, line 15, after "(June 1995)" insert --, and which is the subject matter of an article by M. Rajadhyaksha and James M. Zavislan which appeared in *Laser Focus World*, page 119 (February 10, 1996),--

Page 1, lines 17, 18 and 19, cancel "and which is the subject matter of an article by M. Rajadhyaksha and James M. Zavislan which appeared in *Laser Focus World*, page 119, (February 10996)".

Page 1, line 20, after "or" insert --interference--.

Page 2, line 10, change "Theses" to --These--.

Page 2, line 19, after "of" insert --a--.

Page 5, line 15, before "is" insert --,--; and line 24, change "dis play" to --display--.

Page 6, line 1, after "32" insert --(FIG. 2)--.

Page 6, line 6, after "assembly" insert --37--.

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Page 6, line 15, cancel “%” and insert a degree sign so that it reads --45°--.

Page 6, line 15, change “as” to --is--; and after “shown” insert --at 46--.

Page 6, line 17, change “crustal” to --crystal--; and line 18, delete “structure”.

Page 7, line 1, after “retarder” insert --44--.

Page 7, line 2, change “beans” to --beams--.

Page 7, line 20, after “are” insert --orthogonally polarized, particularly--.

Page 8, line 17, after “Accordingly” insert a comma.

Page 9, line 5, change “upper” to --super--.

In the Claims:

Cancel Claims 1-28.

Please add new Claims 29-42:

29. A system for imaging a section of a medium which receives and returns light from the section and from sites adjacent to the section, said system comprising:

optics for directing light in beams of different polarization in said medium along an imaging plane and collecting returned light from the medium; and

means for generating an image of the section from said returned light in response to a polarization parameter of said returned light.

30. The system according to Claim 29 wherein said beams are capable of overlapping in said medium to reduce the part of said returned light from the sites adjacent said section.

31. The system according to Claim 29 wherein said beams are incident said medium at spots spaced in at least one direction along an imaging plane.

32. The system according to Claim 29 wherein said polarization parameter is the degree of rotation of the polarization of said returned light.

33. The system according to Claim 29 wherein said polarization parameter is a function of the differential circular dichroism or optical activity of the returned light.

34. A method for imaging a section of a medium which receives and returns light from the section and from sites adjacent to the section, said method comprising the steps of:

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directing light in beams of different polarization in said medium along an imaging plane;
collecting returned light from the medium; and
generating an image of the section from said returned light in response to a polarization parameter of said returned light.

35. The method according to Claim 34 wherein said beams are capable of overlapping in said medium to reduce the part of said returned light from the sites adjacent said section.

36. The method according to Claim 34 wherein said beams are incident said medium at spots spaced in at least one direction along an imaging plane.

37. The method according to Claim 34 wherein said polarization parameter is the degree of rotation of the polarization of said returned light.

38. The method according to Claim 34 wherein said polarization parameter is a function of the differential circular dichroism or optical activity of the returned light.

39. An optical coherence imaging system comprising:
a source providing light which is of low coherence;
optics which directs the light from said source into a reference arm and a sample arm to an image plane in a specimen section;
a polarization separator which shears said light into two beams;
a polarization retarder between said separator and said specimen providing said sheared beams each with an opposite sense of generally orthogonal polarization;
an objective for focusing said two beams at spots spaced from each other in said image plane, which beams overlap outside the vicinity of said image plane;
a detection arm into which light is directed by said beam splitter from said reference and sample arms; and
means for providing images in response to interference of light in said detection arm.

40. The system according to Claim 39 wherein said optics comprise:
a beam splitter for directing light into a reference arm and a sample arm to an image plane; and
a scanner for scanning light of the sample arm in said plane in one or more directions.

41. The system according to Claim 39 wherein said separator is one or a Normarski and Wollaston prism.

42. The system according to Claim 39 wherein said orthogonal polarization is generally circular polarization.


Remarks

Amendments to the Abstract and Specification, after page 1, line 3, are the same as amendments made to Parent Application Serial Number 08/966,046.

Claims 1-28 are cancelled, and Claims 29-42 have been added for consideration by the Examiner.

Respectfully submitted,

Dated: August 18, 2000


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IMAGING SYSTEM USING POLARIZATION EFFECTS TO ENHANCE IMAGE QUALITY

Description

5 The present invention relates to imaging systems which enhance image quality by reducing noise which reduces contrast in images especially images obtained from turbid media, such as encountered in biological specimens, and especially dermatological tissue wherein keratin is present. Media, which are turbid, may be characterized by having a high rms refractive index variation and high scattering cross sections.

10 The invention is especially suitable for use in confocal microscopy and especially in laser scanning confocal microscopes, such for example as the Vivascope confocal scanning laser microscope which is sold by Lucid Technologies, Inc. of Henrietta, New York, U.S.A. and described in an article by M. Rajadhyaksha, et al. entitled "*In Vivo Confocal Scanning Laser Microscopy of Human Skin, Melanin Provides Strong Contrast*" which appeared in the Journal of Investigative Dermatology, Volume 104, No. 6 pg. 1 (June 1995) and in the hand held scanning laser microscope which is the subject matter of US Patent Application Serial No. 08/650,684 filed May 20, 1996 in the name of James M. Zavislan et al. and which is the subject matter of an article by M. Rajadhyaksha and James M. Zavislan which appeared in Laser Focus World, pg. 119 (February 1996). The invention is also useful in optical coherence tomography or microscopy.

20 It has been discovered in accordance with the invention, that by illuminating a medium by beams having generally circular polarization in opposite senses (left and right handed circular polarization) images obtained from return light from an image plane or section within a specimen, by responding to circular dichroism and retardation, of the return light (circular dichroism and retardation is intended to include degrees of elliptical polarization), that image distortion, such a produced by scattering sites adjacent to the image plane or section, tends to be minimized or at least reduced to a constant value, while optical signals due to index variations and other optical activity within the image plane or section (region of interest) are

actually detected. Thus correlated noise from scatterers, which produces optical distortion and especially speckle effects in the image, are reduced thereby enhancing the quality of the image. The focal region (image plane or section) may be at the surface of the specimen or embedded in the specimen. Noise due to scattering sites away from the focal region may occur, whether the region is at the surface or embedded in the specimen. The section being imaged, especially in imaging of biological tissue, is of the thickness of a cell, for example about five microns.

Regions adjacent to the section of interest may have an abundance of scatterers both behind and ahead of the section in the direction of propagation of the illuminating beam which is incident on the section. These potential scattering sources are illuminated by the same optical field that illuminate the region of interest. There is a finite probability that return light from these scatterers will pass through a confocal aperture and reach the detector as optical signals from which the image of the section of interest is constructed. The spurious return light may manifest itself as speckle in the image. The use of sheared circularly polarized beams, in accordance with the invention, has been found to reduce such distortion, and especially speckle distortion, thereby providing additional contrast and enhancing the image quality.

Laser scanning confocal microscopy provides image enhancement in that laser light beams are used, especially beams of wavelength, such as in the infra-red range, which are maximally transmitted. The confocal aperture restricts the section which is imaged to the focal region. The probability, nevertheless exists that scattered light from regions away from the focal region will pass through the confocal aperture and produce noise, especially speckle, which distort and reduce contrast in the image which is detected. It has been proposed to use light restricted to one polarization state, but only for surface reflection reduction by eliminating the other polarization state. It has also been proposed to use sheared beams and differential interference contrast to enhance microscope images. Such beams have been

obtained using Nomarski or Wollaston prisms and the technique of using such sheared beams has been referred to as Nomarski microscopy. See D.L. Lessor et al. "*Quantitative Surface Topography Determination by Nomarski Reflection Microscopy*", Journal of the Optical Society of America, Volume 69 No. 2, pg. 357 (February 1979). Nomarski microscopy techniques have also been proposed for use in confocal microscopy. See C.J. Cogswell, "*Confocal Differential Interference Contrast (DIC) Microscopy*", Journal of Microscopy, Vol. 165, Part I, pp. 81-101 (January 1992). Even with Nomarski techniques applied to confocal microscopy, noise distortion, which appears to emanate from scattering sites adjacent to the focal plane or image plane of interest, has not been minimized.

It is a feature of the present invention to further enhance image quality in imaging systems by utilizing circularly polarized beams focused on the image plane thereby obtaining noise reduction in the image, especially speckle noise which may be attributable to scatterers adjacent to the image plane.

The noise reduction system described herein has application to optical coherence imaging often referred to as optical coherence-domain reflectivity, optical coherence tomography or optical coherence microscopy. (See Schmitt et al, *Optical characterization of dense tissues using low-coherence interferometry*, SPIE, Vol. 1889, pps 197-211, July 1993.) In this imaging modality, a low-coherence source is used to illuminate a interferometer with a phase-modulated reference arm and a sample arm. In the sample arm a focussing objective directs light into a sample, often a turbid biological specimen. Only light which is scattered from a depth in the tissue that has equal optical path as the optical path of the reference arm constructively interferes at the detector to provide an electronic signal that represents the optical signal from the sample. This coherence requirement eliminates the need for a confocal pinhole to select the image plane inside the tissue. Optical coherence imaging however, suffers from the same deleterious effect of adjacent scatters as does confocal imaging. This

effect is reduced, however, by the same polarization illumination and detection system previously described.

Accordingly, it is the principal object of the present invention to provide improved imaging systems, and especially imaging systems using confocal microscopy, and more especially laser scanning confocal microscopy.

It is a further object of the present invention to provide improved confocal microscopes and especially improved laser scanning confocal microscopes.

It is still further object of the invention to provide improved confocal laser scanning microscopes which provide images of biological tissue, and especially dermatological tissue.

It is a still further object of the inventor to provide improved instruments using optical coherence interferometry.

Briefly described, a system embodying the invention enables viewing of section of a medium. Light is received by and returned from the section and from sites adjacent to the section. The system utilizes a polarization separator, such as Nomarski or Wollaston prism, and a polarization retarder, such as a quarter wavelength plate, both operative on laser light which is incident on the medium and which are disposed successively in the direction of the incident light. The separator and retarder process the incident light into light which is polarized generally circularly and in opposite senses. This oppositely handed polarized light is incident on the medium in the section being imaged at spots which are spaced laterally nominally in the plane of the section of interest providing interference of light returned from the sites (scatterers) adjacent to the section being imaged. The image may be constructed in response to a polarization parameter, for example the degree of circular dichroism, of the return light.

The foregoing and other objects, features and advantages of the invention, as well as presently preferred embodiments thereof, will become more apparent from reading of the following discussion in connection with the accompanying drawings in which:

FIG. 1 is a schematic diagram of a laser scanning confocal microscope which embodies the invention;

FIG. 2 is a schematic diagram illustrating the polarization processing, in the microscope of FIG. 1, of the incident light and the collection of the return light from an image section which is shown as a focal plane;

FIG. 3 is a schematic diagram showing the collection optics in the return arm of a confocal microscope system of the type illustrated in FIG. 1 which detects the ellipticity of polarization (providing an ellipsometer) and enables the construction of the image in response thereto; and

FIG. 4 is a schematic diagram of an optical coherence imaging system embodying the invention.

Referring to FIG. 1, there is shown a confocal laser scanning microscope wherein the beam, which is made incident on and illuminates a turbid sample 12, is obtained from a single mode laser 14, which in the case where the microscope is used to image a section of dermatological tissue (forming the turbid sample 12) is preferably in the infra-red range. The incident beam from the laser is linearly polarized as indicated by the arrow 16. A polarizing beam splitter 18 passes the incident beam to scanning optics 20.

These scanning optics provide scanning in an X, Y direction, where X and Y are coordinates orthogonal to each other in the image plane. The scanning optics may be an undulating or pivoting mirror and a rotating polygon mirror as in the Vivascope laser scanning confocal microscope referenced above. Orthogonal mirrors may provide the scanning optics, as in the confocal scanning microscope described in the above-referenced publications. The scanning optics is controlled by a computer controller 22 which also collects image data from a photo detector 24 and constructs the image either on a display, printer or a recorder 26.

The incident and return beams are deflected by a mirror 28 toward the sample 12 and pass through an objective lens system 30 to the focal or image plane in the specimen.

Optical polarization processing elements 32 are disposed in the beam path ahead of the objective 30. The return light from the image plane is again deflected by the scanning optics 20 and deflected by the beamsplitter 18 through detector optics (a condenser lens system) 34 to the detector. The detector optics focuses the light at the center of a confocal aperture 36. In order to select the image plane, the objective 30 together with the polarization processing optics 32 (which may be an assembly) is movable under control of the computer controller 22 in the Z direction which is a direction perpendicular to the X and Y direction as shown at 40. So far described, except for the processing elements, the confocal laser scanning microscope 10 is similar to that described in the referenced article and patent application.

The polarization processing optics 32 is provided by a Wollaston, but preferably a Nomarski, prism 42 and a quarter wave phase retarder or plate 44 which interposes a quarter wave or 90 degrees phase delay at the laser wavelength. This retarder 44 may be a plate of transparent, bi-refrigent material such a quartz, calcite, etc. The state of polarization of the incident beam contains polarization components parallel and perpendicular to the optical axis 48 of the upper section 50 of prism 42. For example, linear polarization at 45% as shown in FIG 2. The optical axis of the lower section 52 of the prism is orthogonal to the optical axis 48 of the upper section 50. The optical axes are determined by the crustal structure of the prism structure. Light polarized perpendicular to the optical axis is passed through the prism section without extraordinary refraction. For further and more detailed definition of the optical axis of crystals, see Yariv et al., "*Optical Waves in Crystals*", published by John Wiley and Sons (1984), especially section 4.2.

Because the incident polarization 46 contains components of polarization parallel to both optical axes of the prism sections, the prism 42 splits or shears the incident beam 56 into two linearly polarized beams, A and B. The axes of polarization for the two beams are parallel to each of the optical axes of the two prisms in the Nomarski's prism. The shear is in a direction transverse to the direction of propagation of the incident beam 56. Both beams pass

through a 90° phase retarder with its fast axis 45° to each polarization axis of beams A and B. The beams A and B are focused at spots C and D, respectively in the focal or image plane 58. It will be appreciated that these spots are scanned in X and Y over the image plane in order to provide optical signals from which the image can be constructed, after detection by the
5 detector 24, in the computer 22. Preferably the spots substantially overlap. They are suitably separated by a distance, $D/4$, where D is the Airy diameter of focal spots formed by the objective 30.

The light is returned and collected by the objective 30 and combined inside of the prism 42, and returned as general elliptically polarized beam. The polarization state of the
10 light returned from the spots C and D. depends upon the optical activity and optical retardance, particularly the difference in the average refractive index across the spots C and D. Accordingly, the amount of light from the image plane, which is focused by the condenser 34 and passes through the confocal aperture as the optical signal which is detected by the
15 detector, 24 depends upon the amount of polarization rotation, or the differential interference which produces a phase rotation of the polarization vector. Since the polarizing beamsplitter is set to reflect the polarization orthogonal to the incident polarization 16, towards the detector with greatest efficiency, the intensity of illumination at the detector depends upon the rotation and polarization (in effect the degree of elliptical polarization) which is produced by the
20 material in the sample in the image plane.

Because of the quarter wave plate 44, the incident beams A and B are circularly polarized in opposite senses. Therefore, they have a 180° phase difference between them. Both beams illuminate the noise producing scatterers outside (above and below) the focal plane, because of the nearly complete overlap of the two beams outside the focal region. The beams are spaced from each other in the focal plane (in the image section of interest). It is
25 believed that destructive interference of the light returned from the scattering sites outside of the image section of interest reduces distortion, particularly speckle distortion, of the image.

However, circular dichroism, optical retardance and other optical activity exists between the light returned from the spots C and D. The optical image forming signal from the focal plane may be diminished due to interference effects, but at a much lower rate than the illumination due to the scatterers away from the focal plane. Accordingly, the optical image signal in the return light, is effectively enhanced, while the noise signal is reduced, thereby reducing the noise and increasing the quality and contrast enhancement in the image from the image plane.

Referring to FIG. 3, collection optics in accordance with another embodiment of the invention is illustrated. There, a non-polarizing or leaky beamsplitter 60 passes the laser light beam to the scanning optics and deflects the return beam without completely selecting a component of polarization state orthogonal to the incident polarization, as was the case with the polarizing beamsplitter 18. A retarder 62, which may introduce a variable phase shift, effects the polarization of the return beam. This retarder may be similar to a Babinet-Soliel compensator. This retarder can add a phase shift along any axis to convert the return light to a certain polarization state. The amount of polarization shift depends upon the ellipticity of the polarization of the return beam. A analyzer 64 passes the beam from the retarder 62 to the extent that the polarization state of the polarizer is congruent with the polarization of the analyzer. Accordingly the light or optical signal passed by the analyzer is a function of the ellipticity of the return beam. The return beam is then focused by detector optics 34 at the confocal aperture 36 and then detected by the photo detector 24.

The analyzer and polarizer constitute an ellipsometer. Certain types of optical activity and retardation effectively elliptically polarize the return beam. This is especially the case in biological tissues where the molecular bonds have spiral structure characterizing certain proteins and sugars, which constitute the cells of these tissues. Accordingly the processing of the return light and the detection of the degree of elliptical polarization and ellipse orientation may provide images representing characteristics of biological tissue which are of interest.

Desirably, the photo detector 24 includes amplification and signal conditioning circuits so as to process the electrical signal corresponding to the optical signal for reliable digitization in the computer 22.

FIG. 4 shows an optical coherence imaging system with improved imaging. A low coherence optical source 230 such as upper luminescent diode or femtosecond laser is collimated by lens 235. A linear polarizer 265 polarizes the incident light. The polarization state is oriented to be in the plane of FIG. 4. The light then passes into beamsplitter 240 which is nominally 50%-50% non-polarizing beamsplitter. A portion of the light is directed to a reference mirror 250. Reference mirror 250 is actuated by transducer 255, which may be a piezo-electric actuator. This actuation modulates the phase of the reference arm light.

A portion of the light is reflected toward the sample, first through the polarization separator 200, which is either a Wollaston or Nomarski prism, and next through a polarization retarder 205, such as a quarter-wave plate. The Nomarski prism is oriented such that the incident polarization is at 45° to the optical axes of the birefringent material which make up the Nomarski prism. The fast axis of the quarter-wave plate is oriented at 45° to the linear polarizations emitted from the Nomarski prism. The quarter-wave plate converts the two orthogonally polarized linear polarizations to orthogonally polarized circular polarizations. The angularly sheared, circularly polarized beams are focused to two spots 220 and 221 by lens 210.

Light scattered from the two spots inside or on the object is collected by lens 210 and angularly combined by the polarization separator 200 and directed towards the beamsplitter 240. A portion of the reference and sample light is directed to a photodetector and signal conditioning circuit 245 which may be a silicon photodiode and amplifier. The portion of the light from both arms incident on the detector that is both parallel and coherent will interfere in a detection arm terminated at the detector 245 and produce a phase modulated electric signal which varies synchronously with the reference mirror position. The amplitude of the

modulated signal is proportional to the reflectance of the subject at the point inside the object that has equal optical path as the reference arm to within the coherence length of the source.

As with the confocal system described previously, there are signal contributions from scatterers above and below the surface which equal path as the reference arm. These scatters will produce speckle noise that interferes with the fidelity of the signal. The polarization separator 200 and polarization retarder 205 operate in optical coherence imaging systems in an analogous manner as in the confocal case. The scatters which are outside the surface of equal optical path will be illuminated by the orthogonally polarized spots 220 and 221. The light from these scatterers will be substantially destructively interfere at the detector because the two polarizations have 180° phase difference and illuminate each of the scatters similarly.

Controller 260 controls the scan position of the objective lens 210 through actuator 225. Controller 260 also controls the position of actuator 255 which controls the position of reference mirror 250. The Controller collects the signal and decodes it with the position information of the actuators and drives a display or recorder 270.

From the foregoing description, it would be apparent that there has been provided an improved imaging system, and especially an imaging system which is especially adapted for providing improved confocal microscopes and especially laser scanning confocal microscopes and which is also applicable for optical coherence tomography or microscopy. Variations and modifications in the herein described system, within the scope of the invention, will undoubtedly suggest themselves to those skilled in the art. Accordingly the foregoing description should be taken as illustrated and not in a limiting sense.

Claims

1. A system for viewing of a section of a medium which receives and returns light both from the section, and from sites adjacent to the section that reduces the quality of an image formed from said return light, said system comprising a polarization separator and a polarization retarder, which are disposed successively in the path of the light received by the medium, for processing the light said medium receives into light which is polarized generally circularly in opposite senses and is incident on said medium at spots spaced laterally from each other, thereby providing interference of light returned from said sites and enabling construction of said image in response to a polarization parameter of said return light.

2. The system of Claim 1 wherein means are provided for focussing said light processed by said polarization separator and said rotator into foci at said spots.

3. The system of Claim 1 wherein said polarization parameter is the degree of rotation of the polarization of said return light from said spots.

4. The system of Claim 1 wherein said polarization parameter is a function of the differential circular dichroism or optical activity of the light returned from said spots.

5. The system of Claim 2 wherein said spots are partially overlapping.

6. The system of Claim 5 wherein said focusing means providing said spots is an objective optic and said separation of said foci is about $D/4$ where D is the Airy diameter of said spots.

7. The system according to Claim 1 further comprising a condenser for providing said return light and an objective for focusing said spots, thereby providing a microscope for viewing or construction of an image of said section.

5 8. The system according to Claim 1 further comprising a scanner in the path of said light for said spots with respect to said section.

9. The system according to Claim 8 wherein said scanner is an X-Y scanner, where X and Y are orthogonal directions along said section, an objective focussing said light at said spots, and said polarization separator, polarization retarder and objective being movable in a Z direction orthogonal to said X and Y directions.

10. The system according to Claim 8 wherein said scanner is in the path of said incident and return light.

11. The system according to Claim 10 further comprising a laser providing a beam of said light which is incident on said medium with polarization such that said beam is sheared in a direction traverse to said beam.

12. The system according to Claim 7 wherein said microscope is a confocal microscope having a splitter passing light received by said medium and deflecting said return light to said condenser, a confocal aperture said condenser focusing said return light at said confocal aperture.

13. The system according to Claim 1 wherein said polarization separator is a Wollaston prism or a Nomarski prism each having reflecting portions which have optical axis oriented in directions transverse to each other.

5 14. The system according to Claim 13 wherein said light received by said medium is provided as polarized light substantially linearly polarized along one of said optical axis.

15. The system according to Claim 14 wherein said polarization rotator is an optic providing a phase shift of substantially 90° .

10 16. The system of Claim 1 further comprising polarization responsive optics in the path of said return light for passing, for construction of said image, light having predetermined polarization.

15 17. The system of Claim 16 wherein said polarization responsive optics comprises a polarization beam splitter which transmits said light received by said medium and deflects said return light, which respectively have generally orthogonal polarizations.

20 18. The system of Claim 16 wherein said polarization responsive optics comprises a polarizer and analyzer for passing light with selectable elliptical polarization as the polarization parameter for construction of said image represented by selected optical activity.

25 19. The system of Claim 18 wherein said polarizer is a variable optical phase shifter such that said polarizer and analyzer provide an ellipsometer.

20. Scanning confocal microscope which comprises a laser providing an incident beam, a beam splitter, a scanner for scanning an image plane in a specimen section in generally orthogonal X-Y directions in said plane, a polarization separator which shears said beam into two beams along a direction transverse said incident beam, a polarization retarder providing said sheared beams each with an opposite sense of generally circular polarization, and an objective for focusing said sheared beam at spots spaced in said direction in said image plane, a confocal aperture, a photo detector behind said aperture, and optics for focusing return light deflected by said beam splitter at said aperture.

21. The microscope according to Claim 20 wherein said separator, rotator, and objective are movable together to in a Z direction, generally orthogonal to said X-Y directions thereby selecting different image planes of said specimen.

22. The microscope of Claim 21 wherein said separator is a Nomarski or Wollaston prism.

23. The microscope of Claim 21 wherein said beam splitter is a polarizing beam splitter.

24. The microscope of Claim 21 wherein said beam splitter is a non-polarizing beam splitter and further comprising ellipsometer optics between said beam splitter and said return light focusing optics.

25. An optical coherence imaging system which comprises a source providing light which is of low coherence, a beam splitter which directs the light from said source into a reference arm and a sample arm to an image plane in a specimen section, a scanner in each sample arm for scanning each specimen in generally orthogonal X-Y directions in said plane,

and also in said sample arm, a polarization separator which shears said light into two beams, a polarization retarder providing said sheared beams each with an opposite sense of generally circular polarization, an objective for focussing said two beams at spots spaced from each other in said image plane, a detection arm in to which light is directed by said beam splitter from said reference and sample arms, and means for providing images in response to interference of light in said detection arm.

26. The system according to Claim 25 wherein said separator, rotator and objective are movable together to in a Z direction, generally orthogonal to said X-Y directions thereby selecting different image planes of said specimen.

27. The microscope of Claim 25 wherein said separator is a Nomarski or Wollaston prism.

28. The microscope of Claim 25 wherein said beam splitter is a non-polarizing beam splitter.

IMAGING SYSTEM USING POLARIZATION EFFECTS TO ENHANCE IMAGE QUALITY

Abstract

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The quality of images produced by confocal microscopy, and especially scanning laser confocal microscopy, is enhanced especially for images obtained in turbid mediums such as many biological tissue specimens, by reducing speckle from scatterers that exist outside (above and below) the focal plane region which is being imaged by utilizing sheared beams, both of which are focused to spots in the focal or image plane (region of interest) and polarizing the beams to have opposite senses of circular polarization (right and left handed circular polarization). The return light from the image plane of certain polarization is detected after passing through the confocal aperture of the confocal microscope. Light from scatterers outside the region of interest, which are illuminated by both of the sheared beams, interfere thereby reducing speckle due to such scatterers, and particularly scatters which are adjacent to the image plane. Sheared beams having orthogonal linear polarization, as may be obtained from a Wollaston or Nomarski prism are converted into circularly polarized beams of opposite polarization sense by a quarter wave plate. The optical signals representing reflections from the focal plane are derived by polarizing optics which may either, be a polarizing beamsplitter in the incident beam path or with a retarder and analyzer. The retarder may be selected to provide different polarization shift of the return light, and with the analyzer, detects the degree of elliptical polarization representing the optical activity and circular dichroism producing the optical signal representing the image.

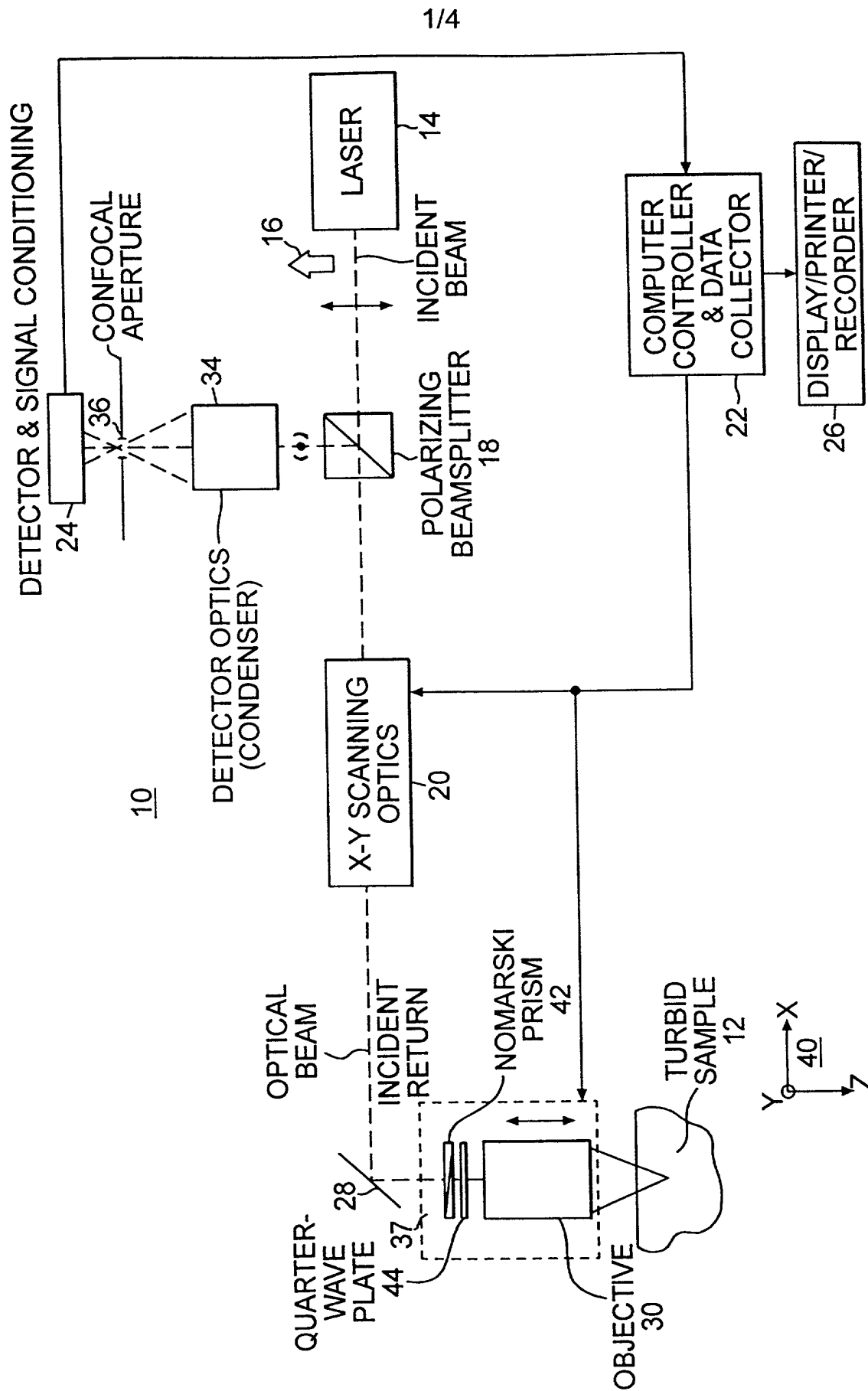


FIG. 1

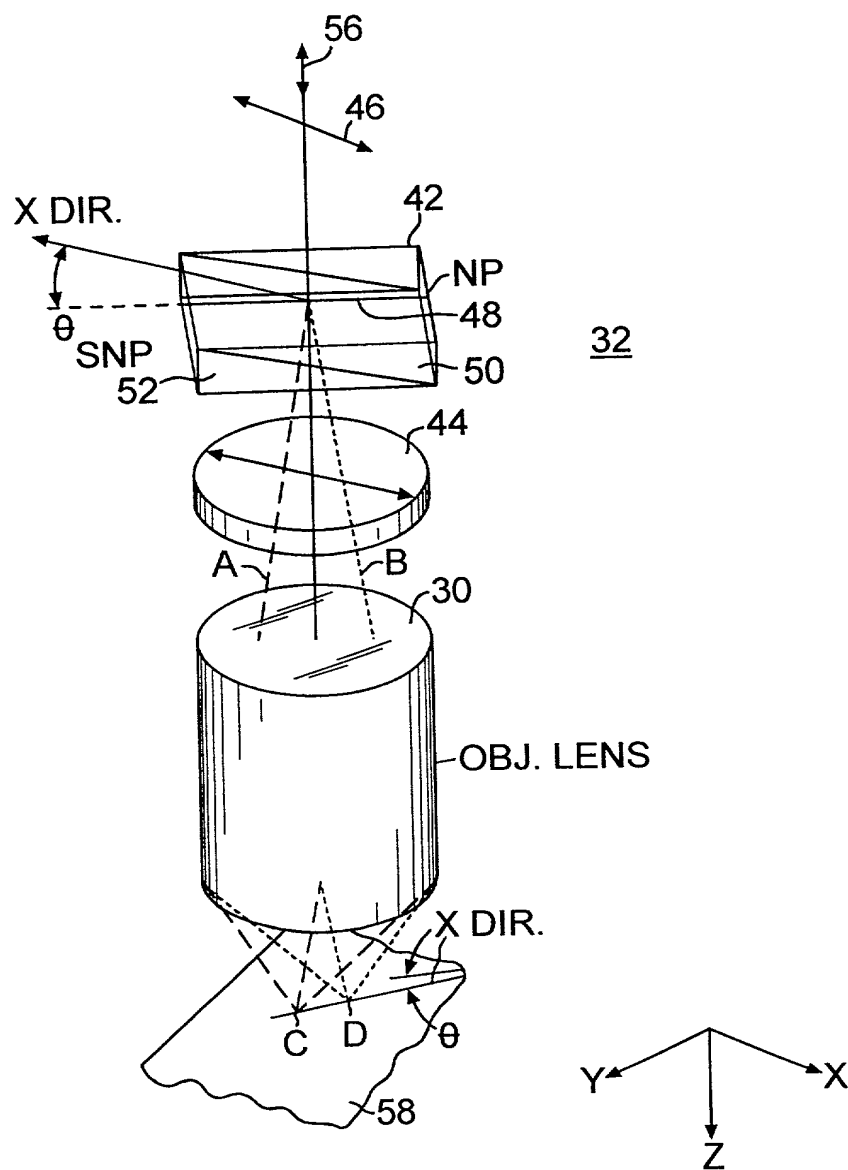
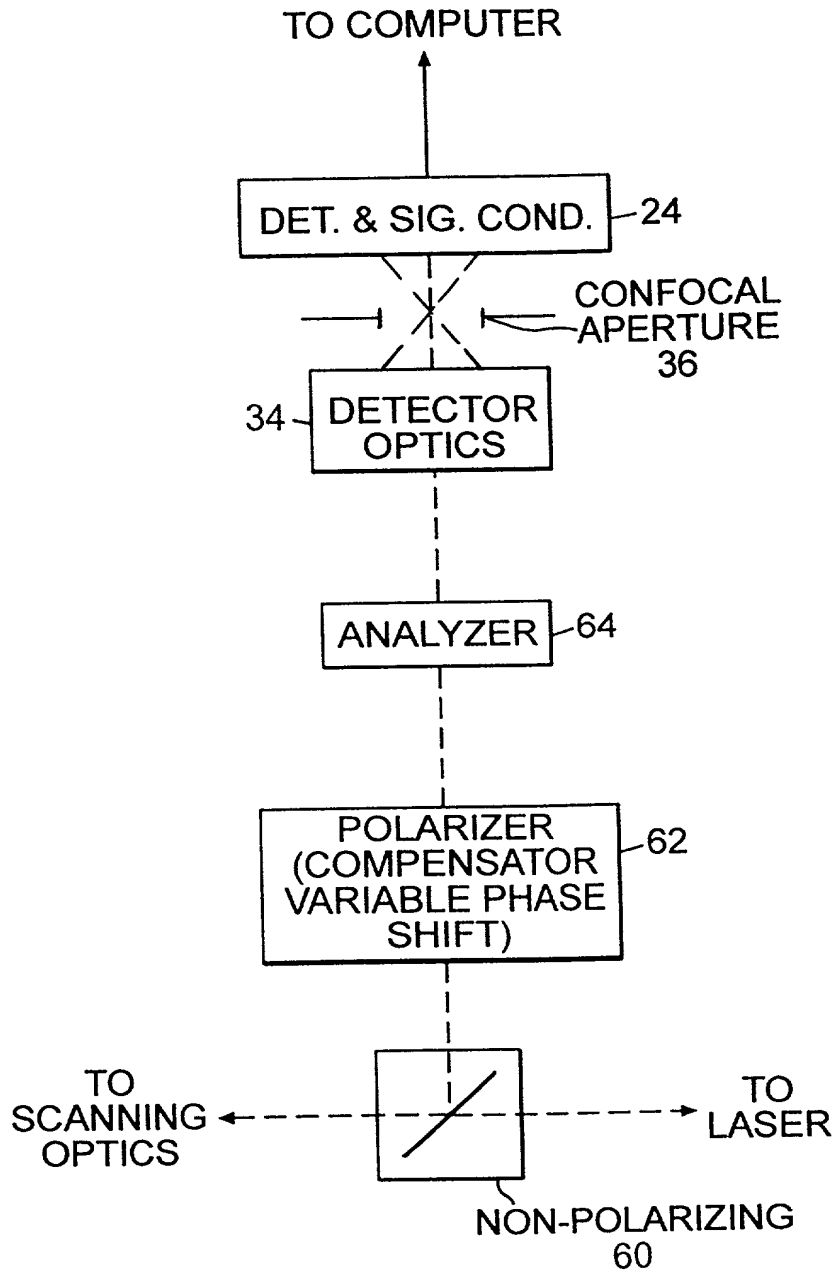


FIG. 2

**FIG. 3**

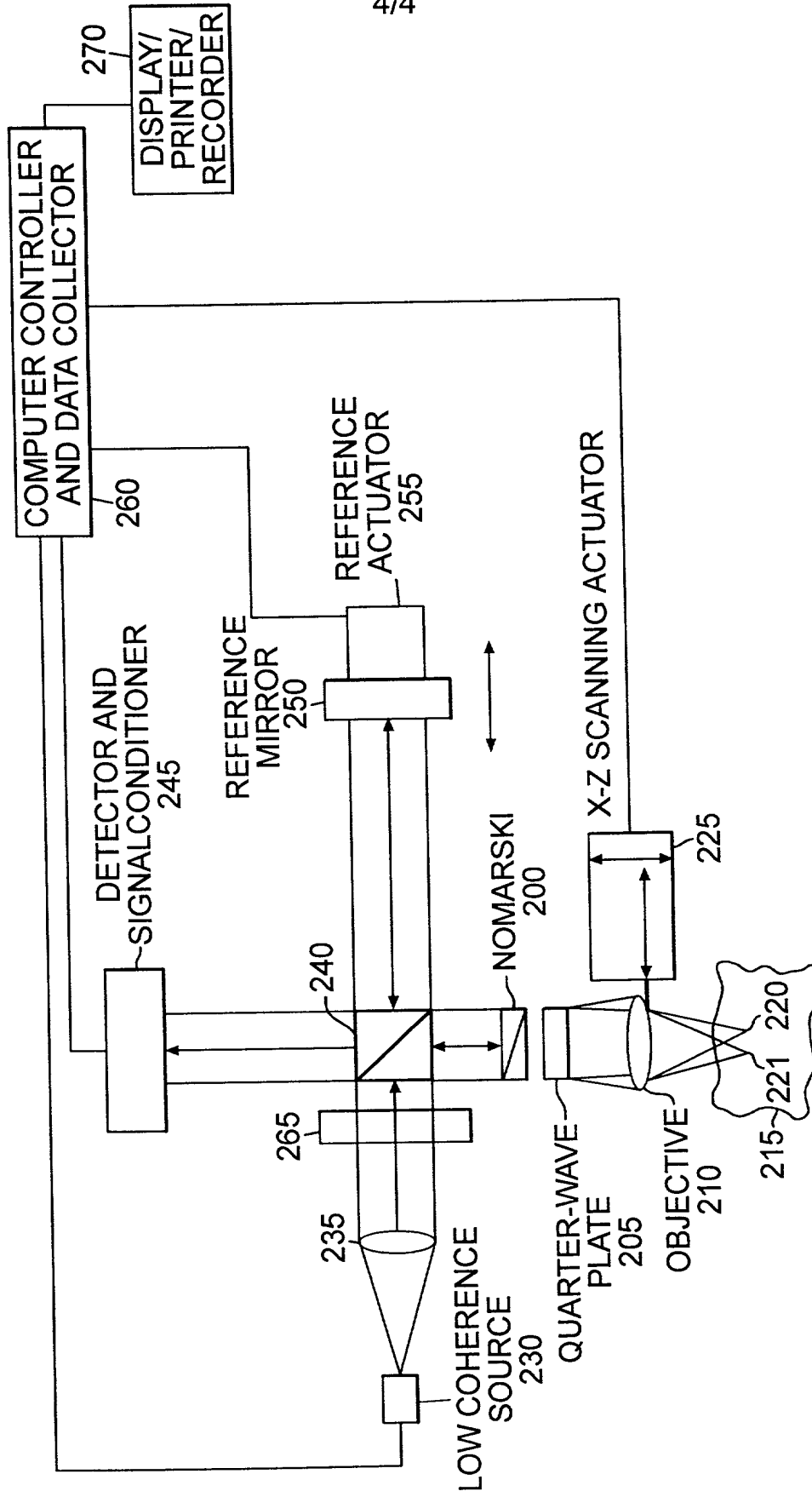


FIG. 4

Docket No.

ML-0459

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

IMAGING SYSTEM USING POLARIZATION EFFECTS TO ENHANCE IMAGE QUALITY

the specification of which

(check one)

☒ is attached hereto.

☐ was filed on _____ as United States Application No. or PCT International Application Number _____ and was amended on _____

(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Priority Not Claimed

(Number)

(Country)

(Day/Month/Year Filed)

☐

(Number)

(Country)

(Day/Month/Year Filed)

☐

(Number)

(Country)

(Day/Month/Year Filed)

☐

I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional application(s) listed below:

(Application Serial No.)

(Filing Date)

(Application Serial No.)

(Filing Date)

(Application Serial No.)

(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112. I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

